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Alyawara Plant Use and Optimal Foraging Theory

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Introduction

Various authors (e.g., Golson 1971; Lawrence 1968; Meggitt 1964; Tindale 1977) have remarked on the importance of seeds in the pre-European diet of central Australian Aborigines. The Alyawara, an Arandic-speaking group, were typical in this respect. They collected edible seeds from nearly half the eighty-five plant species in their traditional subsistence inventory. In the past thirty years, Alyawara subsistence practices have changed dramatically because of the availability of European foods. Nevertheless, native foods continue to play a small but important role in the economies of some communities. Curiously, seeds are now seldom taken by the modern Alyawara, although they are often very abundant and readily accessible. We argue here that this phenomenon is best accounted for by models drawn from the theory of optimal foraging, which seeks to explain subsistance patterns in terms of the costs and benefits of exploiting various resources. Specifically, we maintain that since seeds are expensive to take relative to their nutritional value, they should be used only when the returns from other resources are very low, regardless of their own absolute abundance. This explanation appears to account for the modern Alyawara situation. It also contradicts the commonly accepted notion that hunter-gatherers take plant and animal foods in direct proportion to their abundance or nutritional value, except where considerations of palatability, or "cultural" preference or prohibition, intervene (e.g., Harpending and Davis 1977; Jones 1978; Yellen 1977:64-65).

Having presented this argument, we then consider some more general implications of optimal foraging theory: first, for the explanation of intergroup variation in diet among central Australian Aborigines; then, for current thought about seed exploitation in Australia, its history and its significance for ideas about the pattern and rate of continental colonization. We conclude with some comments about the general value of optimal foraging theory in anthropology.

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The Alyawara Case

Environmental and Ethnographic Background

The Alyawara are a regional population who define themselves by a common language, a dialect of Aranda called Alyawara or Iliaura. Their traditional homeland is centered on the Sandover River, about 250 km northeast of Alice Springs, central Australia (figure 5.1). Most of this country is a rolling sand plain or dune field dotted with low, isolated sandstone ridges, and covered with vast stands of tussock grass and scattered, sometimes sizable patches of scrub forest. The climate is warm and dry (Slatyer 1962). Summer (December-

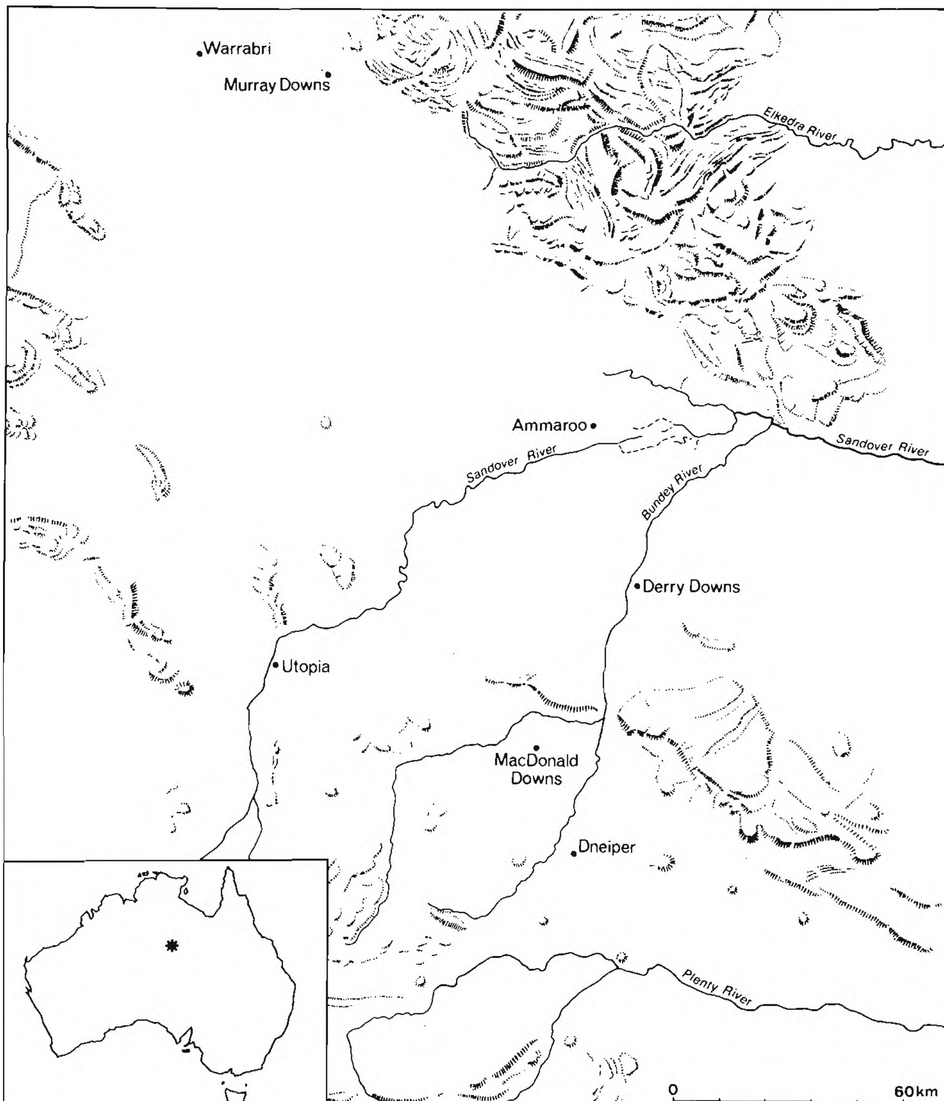

Figure 5.1. Traditional Alyawara Territory and Locations of Modern Settlements.

February) high temperatures average 37°C, and often exceed 40°C for days at a time. Night-time lows average 22°C. In winter, daily highs average 21°C, nightly lows about 3°C. Average annual precipitation is about 300 mm (12 in), most of it falling in violent summer thunderstorms. Seasonal and annual totals are both highly variable.

In pre-European times, the Alyawara lived in small, widely scattered groups, each consisting of a few closely related families. Regional population density was low, probably about one person per 50-90 km^2. Subsistence economy was based entirely on hunting and gathering. Local groups moved frequently from site to site over a wide area during the course of a year, depending on the distribution of food and water (see Gould 1969; Spencer and Gillen 1927; Strehlow 1965 for comprehensive descriptions of traditional life among neighboring groups).

Some aspects of Alyawara life have changed dramatically in the past half-century, largely because of the establishment of local European cattle stations (Stanley 1976; Stevens 1974). Most Alyawara now live in semipermanent settlements of 20-200 people located near station homesteads on or just outside the limits of their traditional territory. Some are employed in the cattle industry, but most are heavily dependent on government welfare for basic subsistence. Apart from these changes, the Alyawara remain strongly traditional in many respects. Alyawara itself is still the basic language although English is spoken by many. There has been little exposure to European religion or formal education. Traditional marriage and kinship systems are essentially intact.

Until the mid-1970s, the Alyawara were scarcely reported in the anthropological literature. Early research among southern bands is described by Tindale (1931) and Cleland (1932). More recently, Yallop (1969 1977) and Denham (1972 1974ab 1975 1977 1978; Denham, et al. 1979) have published major works on language, territory, population structure, kinship, and nonverbal behavior. The data presented here were gathered in the course of sixteen months of ethnographic and archeological fieldwork during 1973-78 in the area around MacDonald Downs homestead (O'Connell 1977abc).

Traditional Subsistence

In pre-European times, Alyawara diet included more than 120 species of native animals, insects, and plants. There are no quantitative data on the relative importance of various taxa, but informants raised under traditional conditions consistently identify eight marsupials, two birds, two or three lizards, cossid larvae (also known as witchitty grubs), about fifteen seeds, two roots, and four to six fruits as having been eaten regularly (see table 5.A.1 in the appendix to this chapter). Nearly all these species were once encountered throughout Alyawara territory, but most of the marsupials (with the exception of red kangaroo and euro) are now locally extinct or much reduced in number. Large animals and birds were taken by men armed with spears and throwing sticks; burrowing animals and roots were dug by men and women alike with wooden scoops and digging sticks. Seeds were collected by women and processed with a variety of tools and facilities, including seed beaters, winnowing trays, threshing pits, grinding slabs, and handstones.[1] None of these foods was stored, with the exception of some fruits which were occasionally kept dried in small quantities for brief periods (see Cleland 1932; O'Connell, Latz, and Barnett, n.d.; Spencer and Gillen 1899 1927; Tindale 1974 for detailed descriptions of traditional hunting, collecting, and processing techniques and technology).

1. The terms *forage* and *collect* and their respective derivatives are used here synonymously, not in the sense of Binford (1980).

Modern Subsistence

Since the mid-1950s, when the native welfare system came into effect locally, Alyawara diet has consisted largely of European foods distributed in the form of weekly rations. The kinds and quantities of items given to each household vary somewhat depending on its size and composition, but the average family of five or six, including two adults and three to four children, receives about 20 kg flour, 2 kg treacle or jam, 5 kg refined white sugar, 1.5 kg powdered milk, 0.5 kg tea, and a small quantity of plug tobacco. Households with cash incomes from wages or welfare benefits also purchase extra ration items, as well as tinned fruit and meat, sweet biscuits, candy, and soft drinks at the small stores run by most cattle station operators. Fresh beef is frequently available for sale in many settlements. In 1974, average weekly sales were as high as 1.0-1.5 kg per capita.

Hunting continues to play an important role in some communities, especially those along the southern tier of Alyawara territory. Men armed with small-caliber rifles and shotguns regularly take red kangaroo, euro, and bustard, an activity which contributes up to seventy per cent of total per capita meat intake. Women still forage for native foods, though far less often than they did under traditional conditions, largely because of the availability of rations. Even the most active collectors seldom go out more than once a week, and many women rarely go. The return from this activity is relatively low, probably about five per cent of total food intake in those households where it is most important.

Plant Collecting at Bendaijerum

The best available data on Alyawara plant collecting are from the settlement known as Bendaijerum or MacDonald Downs (Denham 1975 1978; O'Connell 1977c). In 1974-75, this community included a European homesteader and his family and about 100-125 Alyawara and eastern Aranda. The European employed about 10-15 Aborigines as stockmen and also distributed rations and welfare checks and ran a small cash store. Many of the Aboriginal men hunted regularly on foot in the area immediately around the settlement and by car in the grasslands 20 km to the southwest. Both men and women collected plant foods, the women far more often than the men.

Plant collecting took place in three major plant communities or habitats (figure 5.2).

Mulga woodland. The mulga woodland community covers about seventy-five per cent of the area within 10 km (two hours walking distance) of Bendaijerum. The dominant species is mulga (*Acacia aneura*), a low scrubby tree 3-6 m high, typically distributed in dense linear groves 200-400 m long and 10-100 m wide. Groves are separated by open lanes, or "intergroves," which are several times larger and covered by low shrubs (especially *A. kempeana* and *Cassia* spp.) and grasses (especially *Eragrostis eriopoda, Panicum* spp., and *Astrebla* spp.).

Riverine floodplain. Bendaijerum sits between two major watercourses, Bundey and Frazer creeks, which run together about 15 km northeast of the settlement. These streams carry runoff for brief periods after rain, but are otherwise dry, at least on the surface. Their channels are lined with gallery forests of river red gum (*Eucalyptus camaldulensis*), coolibah *(E. microtheca)*, and ghost gum *(E. papuana)*; their broad floodplains covered by open park lands in which ironwood (*Acacia estrophiolata*) and coolibah trees and various grasses (especially *Panicum* spp.) are prominent elements. This community covers twenty-five per cent of the area within two hours walking distance of Bendaijerum.

Sandhills. A prominent sandstone ridge 12 km north of Bendaijerum marks the southern limit of a broad, rolling sand plain which stretches more than 100 km north across the heart of Alyawara territory. The primary plant cover is spinifex, a collective term for several species of tough, spiky tussock grasses (*Triodia* spp., *Plectrachne* spp.). The most common trees are scrubby acacias and eucalypts, notably *A. aneura, coriacea, cowleana, dictyophleba,* and *kempeana,* and *E. gamophylla* and *pachyphylla.* Where the climax community has been disturbed, especially by fire, bush potato (*Ipomoea costata*), native tomato (*Solanum* spp.), and various grasses are usually abundant. Low-lying areas, where runoff from ridge lines and other high ground collects after rain, are covered by dense stands of mulga woodland. The sandhill community is about two hours walking distance from Bendaijerum, but may be reached by car within thirty minutes.[2]

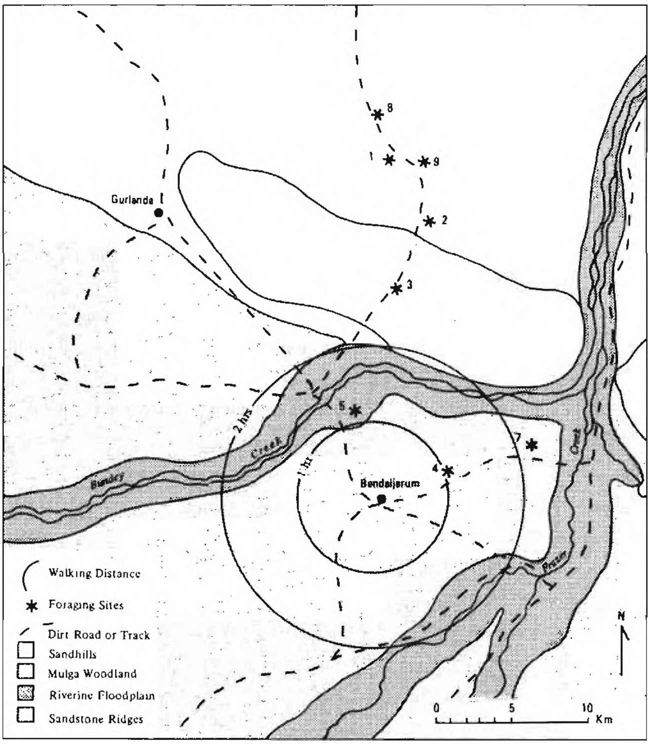

Figure 5.2. Plant Communities (habitats) near Bendaijerum (MacDonald Downs). Site 6 is in the sandhill community west of the area covered by this figure.

The condition of plant resources in these communities during 1974-75 is summarized in figure 5.3. The data are incomplete in that not all resources were monitored consistently throughout this period, but the information available should be sufficient for this discussion. Quantitative analyses of plant collecting are based on a sample of nineteen foraging events, eighteen of which took place between May 1974 and March 1975 (table 5.A.2). The sample is small, representing only 12%-15% of the estimated 100-125 collecting trips originating from Bendaijerum during the May-March interval; and some of the trip records are incomplete. Still, casual observations of collecting activities over a five-year period

2. Though distinctive in some respects, vegetation on the sandstone ridges at the southern edge of the sandhill community (figure 5.2) can be considered the equivalent of that in the latter area for purposes of this analysis (Perry 1962).

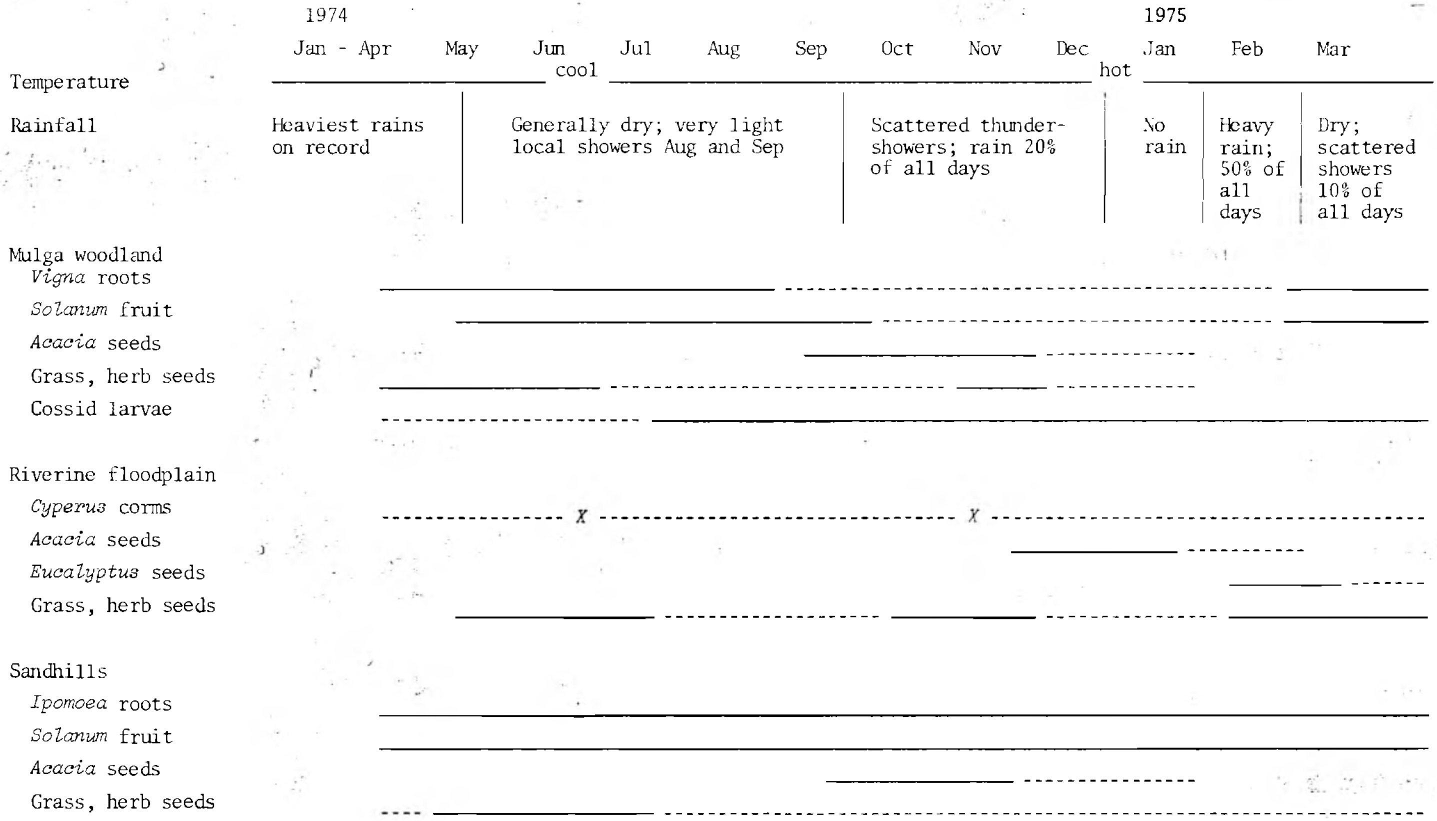

Figure 5.3. Availability of Traditional Plant Foods in Plant Communities near Bendaijerum, 1974-75. Solid horizontal lines indicate periods when resources were observed to be available; dashed lines mark periods when resources were likely to be available given rainfall and temperature conditions. *X* = isolated observations.

in the same area have convinced us that the sample is broadly representative. It is notably exceptional only in that it includes a disproportionate number of trips in which a motor vehicle was used for transportation. In all these instances, the vehicle was the long-wheel-base Toyota Land Cruiser belonging to one of the authors. Except as otherwise indicated in the notes on table 5.A.2, Alyawara collectors initiated the planning for these trips and made all decisions about destination, route, and length of stay at the collecting site. As we shall see, the use of the vehicle, though unusual, actually enhances our understanding of the principles which underlie foraging decisions (see also Winterhalder, chapter 4, above).

Some additional comments on table 5.A.2 are in order. When the vehicle was used for transportation, the party traveled to one or more specific foraging sites. These are numbered on table 5.A.2 and keyed to figure 5.2. When the party traveled on foot, resources might be collected at any time; thus a general area (e.g., mulga woodland east of Bendaijerum) is indicated rather than a specific site. Number of collectors is the number of individuals actually engaged in food collecting. If others were present, as they often were, they are listed in the notes on the table. Main items collected are those gathered and brought back to the settlement. Other resources were occasionally taken in small quantities and eaten in the field; these too are listed in the notes. Total trip time is that between the time the party left the settlement and the time it returned. Time on site is total time spent at each collecting site; this was not recorded for trips made entirely on foot. Processing time is that spent preparing resources for consumption after they had been collected. It includes cleaning, separation of seeds from pods or chaff, grinding, and cooking. Calories per forager hour is the average return in energy per unit of time spent traveling, collecting, and processing.

During late fall and winter (May-July) 1974, plant foods were abundant in all habitats near Bendaijerum owing to very heavy rains during the preceding summer. Alyawara women foraged on foot in the mulga woodland north and east of the settlement, some as often as once or twice a week. Their primary target was *Vigna lanceolata*, or "native yam," a carrot-sized root found in small numbers in moist, well-shaded spots throughout the area. They also collected two species of lizard (*Amphibolarus* sp., *Varanus* sp.), small quantities of *Solanum* fruit, *Lysiana* berries, and tender *Leichhardtia* leaves, all whenever encountered. *Leichhardtia* leaves, *Lysiana* berries, and most *Solanum* fruit were eaten at the collecting site; *Vigna* roots and lizards were brought back to the settlement, as were *Solanum* fruit if available in any quantity (say, more than 0.5 kg). *Vigna* and lizards were roasted in the ashes of hearths; solanums were rubbed by hand to remove any grit and eaten without further preparation. Total returns for these trips were about 2.5-3.0 kg per active collector, or about 0.4 kg per collector-hr, including travel, collecting, and processing time.

Collectors visited the floodplain community far less often. Only one trip (event 7) was recorded in the four-month period May-August, and we doubt that more than one or two others, if any, were taken. The principal target of the recorded trip was *Cyperus* sp., a small corm roughly the size of a shallot, found in some abundance in small patches where the soil is fine, moist, and well shaded. In the one instance observed, five collectors brought 8.0 kg back to camp after eight hours total time in the field, for an average of 1.6 kg per collector, or 0.2 kg per collector-hr.

Whenever the ethnographer's vehicle was available, women organized trips to locations in the sandhill community north and west of the settlement to collect *Ipomoea*, or "bush potato," a large tuber up to 1.0 kg in weight which is common in disturbed areas in this habitat. Their favorite collecting spot was a large abandoned campsite (site 1), about 25 km north-northwest of Bendaijerum; but on one occasion they insisted on traveling to a site on the Sandover River (event 9, site 6), 95 km west of Bendaijerum where they thought *Ipomoea* would be particularly abundant. On nearly all these trips, collectors took *Solanum* (esp. *centrale), Vigna, Leichhardtia* (both fruit and leaves), and *Varanus* whenever encountered. Some *Solanum* and all *Leichhardtia* were eaten in the field without preparation, while *Ipomoea, Vigna*, lizards, and *Solanum* were brought back to camp. *Ipomoea* were scraped with sticks or knives or rubbed by hand to remove grit, and cooked for 15-20 minutes in small, specially prepared roasting pits. The other resources were treated as described above. The return on these trips was relatively high. Average weight of all foods brought to the settlement was 5.5 kg per collector, or about 0.7 per collector-hr.

Trips to the sandhills were also made under other circumstances. Alyawara men occasionally visited these areas while working as stockmen, or when acting as guides or ethnographic informants, or in the course of infrequent long-range hunting trips. In these situations, they collected *Ipomoea* and *Solanum* whenever possible, often in substantial quantities. Also, individual families sometimes arranged trips to the sandhills in their own vehicles. In May 1974, for example, several families traveled by car to a site near Derry Downs, 50 km north of Bendaijerum, where they stayed more than a week collecting *Ipomoea* and *Solanum*, both of which were very abundant there. When these resources were exhausted, the people returned to Bendaijerum. Although many Alyawara own cars or light trucks, trips like this are not common because the vehicles are generally in poor condition and are rightly considered unreliable on the badly maintained tracks one must travel to reach the more productive sandhill patches.

From late winter through midsummer (January 1975), women continued to forage primarily in mulga woodland, generally traveling on foot, but sometimes in the ethnographer's vehicle. Their primary target was cossid larvae, which they dug from the shallow roots of cassia and acacia shrubs. *Solanum* and lizards were also taken, as was the occasional *Leichhardtia* fruit. The average return from these trips was 1.5 kg per collector, or about 0.2 kg per collector-hr.

There were no visits to the floodplains during this period, and only three recorded trips to the sandhills. One (event 13) was made to collect the large but still unripened seeds of *A. coriacea*; and on another (event 16), the target was *Solanum centrale*. Both trips were organized by the ethnographer. Collectors were given choice of habitat and site on the first trip, but site only on the second. The third incident (event 12) took place on a plant-collecting trip organized for botanist Peter Latz, when a sizable patch of *Ipomoea* was discovered unexpectedly. Two of the men acting as guides quickly collected 4.0 kg of *Ipomoea* and a small quantity of *A. coriacea* seeds. This was the only time *Ipomoea* was collected that season.

During February 1975, heavy rains prevented supplies from reaching Bendaijerum for nearly two weeks, and ration stocks became depleted. In response, women foraged more frequently, this time exclusively in mulga woodland. Though the ethnographer's vehicle was available at this time, roads were so wet that it could not be used. Cossid larvae were the principal prey, although *Vigna* roots were collected again for the first time since the preceding winter.

Summary

Though admittedly limited, these observations present us with a very striking fact.

Of the eighty-five plant species identified by the Alyawara as edible, less than a dozen were collected during the study period, and of these, only three (*Ipomoea*, *Vigna*, and *Solanum centrale*) were regularly taken in any quantity. The nearly complete absence of seeds from this group is most surprising. Of the thirty-nine seed-producing species on the traditional list, only one--*Acacia coriacea*--was ever collected by choice, and then only during a brief period just before the seeds became fully ripe. Two other species were also taken (*A. aneura*, event 11; *A. cowleana*, event 13a), but only because of the ethnographer's request for a demonstration of processing and collecting techniques. Although the importance of seeds in the pre-European diet cannot be assessed in strictly quantitative terms, every knowledgeable informant insists that they were eaten regularly and in substantial quantities. Tindale (1974 1977 n.d.) and other observers who visited the Alyawara under traditional conditions make the same observation. This makes the recent lack of attention to seed resources all the more remarkable.

The failure to take seeds cannot be explained by lack of availability or access. At least five edible species (including *Acacia aneura* and *kempeana*, *Eucalyptus microtheca*, *Eragrostis eriopoda*, and *Panicum* spp.) could have been collected within a 10-km radius of Bendaijerum, and an additional four or more (including *Acacia cowleana* and *dictyophleba*, *Eragrostis* spp., *Panicum* spp.) were within easy reach by car. Moreover, the unusually heavy rains of late 1973 and early 1974 had produced abundant seed crops in all species, especially the acacias. Differences in the palatability of seeds relative to other foods are also unlikely to provide an explanation. Though we recognize that cross-cultural assessments of taste appeal can be misleading, one of us (JOC) would argue that seed paste is at least as tasty as *Vigna* or *Ipomoea* roots. More important, the Alyawara themselves never expressed any negative attitudes toward seeds as food. Finally, we note that the availability of flour as a ration item also fails to explain this behavior toward seeds. As we shall show, seeds have been used in the recent past when flour was as available as it was during 1974-75.

We are left with two intriguing questions: Why ignore seeds that were traditionally important, currently abundant, and immediately available, in favor of grubs, roots, and fruit that were less common and could be taken only by walking or driving long distances? Why take one seed species (*A. coriacea*) found no less than 25 km away rather than several others which were abundant less than one kilometer from the settlement? We think both questions can be answered through an application of optimal foraging theory.

Optimal Foraging

The Optimal Diet Model

We use two models derived from optimal foraging theory in the analysis of Alyawara plant use. One describes optimal diet in a uniform or fine-grained environment; the other pertains to choice of foraging sites or areas in a "patchy" or coarse-grained environment.[3] The optimal diet model predicts that in an area or "patch" where resources are encountered

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3. Both are reviewed in detail elsewhere (see Winterhalder, chapter 2, above, and references). In applying them here, we assume that human hunters maximize energy return relative to time invested, and that behavioral or technological practices which increase the likelihood of procuring a particular resource or reduce the time required to take that resource will spread. The first of these assumptions may seem inconsistent with the common ethnographic observation that hunters spend relatively little time on the food quest (Lee 1965; Sahlins 1968 1972). However, energy may be maximized *either* by taking the greatest amount of energy possible in the time available, *or* by investing the least time necessary to obtain given amounts of energy (Schoener 1971). The latter strategy matches the behavior observed among most modern hunters.

at random in proportion to their abundance, a predator will take a resource item only if the returns gained from collecting and processing, or "handling," it are greater than those likely to be gained from searching for and handling an item of higher rank, that is, one which produces a better return from the investment made in collecting and processing. If the return from the item at hand is less, the model predicts that it will be ignored and that the predator will continue to search for higher-ranked resources. If time and energy are used as convenient measures of costs and benefits, this means that resources are included in or excluded from the diet as a function of (1) their rank in terms of energy gain per unit of handling time relative to other resources; and (2) the abundance of higher-ranked resources, or, more precisely, their encounter rate. As the encounter rate for high-ranked resources goes up, low-ranked resources will be eliminated from the diet, and conversely, regardless of the absolute abundance of the low-ranked resources (MacArthur and Pianka 1966; Emlen 1966; Schoener 1971; Charnov and Orians 1973; Pyke, et al. 1977). At the same time, even very rare resources will be included in the diet, provided they produce a relatively high return on handling time (Royama 1970). The model also leads to the expectation that foragers may react quite differently to the same resource, depending on the characteristics of other resources available in a given situation.

If Alyawara collectors are foraging optimally, the resources they take in each patch will depend on the relative energy return per unit of handling time for each resource, and the average return from collecting in that patch. Any resource which yields a return on handling time higher than the average return for the patch will be included in the diet; any resource with a lower return will be excluded. This can be stated formally:

For all items in the optimal set,

$E^*_i/h_i \geq E_p$ where

E^*_i = energy (kcal) per unit weight (kg) of resource i

h_i = gathering and processing time ($g_i + p_i$, in hr) for each resource i

E_p = $E/(T_s + T_g + T_p)$

E = total energy in resources gathered per collector

T_s = total search time within patch

T_g = total gathering time per collector for all resources gathered

T_p = total processing time per collector for all resources gathered

If the encounter rate for high-ranked resources goes down, then search time goes up, the average return for the patch falls, and new items are added as their rank E^*_i/h_i equals or exceeds E_p, and conversely (Charnov and Orians 1973; Charnov 1976b; Pulliam 1974; Schoener 1971; MacArthur and Pianka 1966; MacArthur 1972).[4]

For purposes of this discussion, we assume that despite minor nonrandom variation in the distribution of resources, the mulga woodland around Bendaijerum can be considered a single patch. Sandhill habitats are more complex in that they contain relatively small, bounded areas in which the climax plant community has been disturbed by various processes (notably fire or human occupation) in such a way as to permit the growth of potential subsistence resources, including *Ipomoea, Solanum* spp., and various seed-producing grasses. These disturbed areas are the focus of Alyawara foraging activities in the sandhill habitat,

4. Note that travel time to and from the patch is not included in this model. If it were, one would predict that, all else being equal, increasingly lower-ranked resources would be added to the diet as travel time to patch increased. On the contrary, foragers should choose *only* that set of resources which produces the best return per unit of time expended once they enter the patch, regardless of the distance traveled to reach the patch.

and are called sandhill *patches* to distinguish them from the climax grassland, which is comparatively poor in resources. The small stands of mulga woodland found in sandhill country are also distinguished as separate patches. Floodplain habitats are not considered in this discussion for lack of data.

Energy returns per forager-hour (E_p) in mulga woodland and sandhill patches are listed in table 5.A.3 along with energy returns per unit of handling time (E^*_i/h_i) for each resource collected. Estimates of handling time were difficult to derive since the field notes did not consistently separate this value, except in the case of seeds. Nevertheless, we have arrived at rough but reasonable approximations of these figures by considering the general features of each resource (e.g., average size of individual units) and the time limits suggested by the events sampled. These figures are presented in table 5.A.4. Comments on their derivation are found in the notes for that table.

Now consider the foraging behavior in each patch type. On eleven visits to sandhill patches (excluding event 13a, a seed-processing demonstration), energy returns ranged from about 750-5,200 kcal per forager-hr searching, collecting, and processing. Eight visits produced returns in 2,000-4,000 kcal-per-hr range. Resources taken in quantity were *Ipomoea* roots, *Solanum* fruits, and unripened *A. coriacea* seeds. In each instance, returns per unit of handling time for the resource were well above the average returns for the patch. Although several species of ripe seeds were available in these patches (see figure 5.3) and often encountered, they were never taken because returns from other, higher-ranked resources never fell low enough. *A. coriacea* seeds (event 13b) were collected only in the brief period after they reached maximum size and before they hardened, when handling time is relatively low and energy returns correspondingly high. Foraging behavior in this habitat is clearly consistent with the predictions of the optimal diet model.

Returns from foraging in mulga woodland are low compared with those from the sandhills. Totals for ten incidents ranged about 200-800 kcal per forager-hr in patch, and in all but one case they were less than 600 kcal per hr. *Vigna* roots, cossid larvae, and lizards (*Amphibolarus*, *Varanus*), all of which have E^*_i/h_i values greater than 1,400, were the principal resources taken.[5] With one exception (event 11, a collecting demonstration), ripe seeds were ignored entirely even though E_p values in eight of the nine other cases were equal to or less than those to be gained from handling seeds (500-600 kcal/hr). This suggests that foragers would have been acting more efficiently by including these resources in their diet, especially in the spring (October-November) when acacia seeds were extremely abundant in the area immediately around Bendaijerum. In other words, Alyawara foraging behavior in these eight events fails to fit the optimal diet prediction about the threshold at which lower-ranked resources will be added.[6]

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5. The shift from *Vigna* to cossid larvae in late winter and back again in late summer deserves special comment here, in that it probably reflects small but important variations in encounter rate and forager search patterns. *Vigna* roots are marked above ground by a distinctive vine which flourishes during wet periods, but dies back as conditions become drier, making the roots more difficult to locate. Grubs, on the other hand, are found in the shallow lateral roots of acacias and cassias, which are hard to spot when the soil is moist. As it dries, however, fine cracks appear on the surface just above the root line, and are easily seen by experienced collectors. During the first few months after the heavy rains of summer and early fall, 1974, foragers took *Vigna*, but no grubs. As the ground dried during midwinter, *Vigna* became progressively more difficult to find, even though the roots themselves were still present. Foragers apparently reacted by shifting their attention to grubs. This pattern continued till the following summer when the heavy rains of mid-February prompted renewed growth in *Vigna*. As soon as the vines became visible, collectors began taking this resource again.

6. It is interesting to note that more kinds of resources are consistently collected in the mulga woodland than in the sandhills. This expansion in diet diversity where average returns per forager are lower is the pattern predicted by the optimal diet model.

One explanation for this apparent inconsistency is that the cost of collecting seeds has been underestimated, at least in this particular situation. During 1974-75, the standard plant-collecting kit maintained by women at Bendaijerum included a metal digging stick and one or more carrying devices, such as a wooden tray, plastic bucket, billy can, or some combination of these. With this kit, a woman could collect and process roots, burrowing lizards, and cossid larvae, but not seeds. The manufacture and maintenance of seed-grinding tools would have increased the cost of handling seeds, at least initially.

If this were true, we would expect that where the encounter rate for higher-ranked resources was lower, or foraging activity more intensive (a factor which would both deplete the high-ranked resources *and* spread the cost of maintaining seed-processing gear over a larger number of collecting incidents), seeds would enter the diet. In this connection, it is interesting to note that seed-processing tools are common in household camp debris at Gurlanda B, an abandoned settlement thirty kilometers northwest of Bendaijerum (figure 5.2), occupied in 1971-73. Because of the distance to the store and the limited availability of reliable transport (Denham, n.d.), residents of this settlement had no regular daily access to European foods, though they still received weekly rations, including flour. They may have relied more heavily on native plant resources than did the people at Bendaijerum, but, more important, the abundance of these resources had been reduced by drought conditions which had prevailed in this part of central Australia for several years (Denham, n.d.). Under these circumstances, energy returns from the sandhill and mulga woodland patches around Gurlanda probably fell low enough that it became efficient to take seeds. As the preceding discussion has indicated, the drop need not have been far below 1974-75 levels to make these resources part of the optimal diet. Though the data are limited, they suggest that Alyawara foraging behavior may be explained by a cost-benefit analysis which adds the cost of manufacturing and maintaining processing gear to the variables of the optimal diet model.

These same data also indicate why seeds were so important in the traditional diet. In the absence of European foods, the pressure on native plant resources would have been much greater. Moreover, collectors can apparently deplete certain high-ranked resources with surprising speed, even in a good year. In the next section, for example, we suggest that *Ipomoea* may have been cropped completely from a one-kilometer-square patch after only three visits by collectors. Given this, it should not be surprising that seeds were a central element in past diets.

The Patch Choice Model

Now consider a second closely related question. In situations where resources are differentially distributed in kind and quantity among a series of habitats or patches, as is the case at Bendaijerum, how do foragers decide which patches to exploit? Optimal foraging theory predicts that under such circumstances, collectors will operate in that patch or set of patches which produces the best return in energy for time spent traveling to the patch, searching it, and gathering and processing the resources found there (Charnov and Orians 1973; MacArthur and Pianka 1966; Pyke, et al. 1977; Orians and Pearson 1977). Stated formally, foragers will maximize E_n, where

$E_n = E/(T_t + T_s + T_g + T_p)$

E = total energy gained from all resources gathered per collector

T_t = total travel time to and from the patch

and T_s, T_g, and T_p are defined as above. Within each patch, resource exploitation should follow the predictions of the fine-grain, random encounter model. As relative returns from different patches change over time (e.g., with the seasons, or as the forager depletes resources), the optimal choice will change accordingly.

If Alyawara foraging behavior is consistent with the optimal diet model, we might expect it to fit the patch choice model as well. E_n values for six trips to sandhill patches alone range about 800-1,950 kcal per forager-hr (events 2, 4, 9, 12-13, 16; see table 5.A.2). All these trips involved the use of the ethnographer's vehicle for transport. Eight trips to mulga woodland alone yielded only 250-850 kcal per forager-hr (events 5-6, 10-11, 14-15, 17-18). Three of these trips were by car; the other five were on foot. These figures suggest that foragers operating from Bendaijerum should visit the sandhills whenever they have access to motor vehicles.[7] On nine occasions when the ethnographic vehicle was available, *and* the choice of destination left entirely to the foragers, they elected to travel to sandhill patches five times.

Among these five, events 8 and 9 merit special comment. Event 8 was the third occasion after the beginning of the 1974-75 study period that foragers had visited site 1, an abandoned settlement twenty-five kilometers north of Bendaijerum. On the first trip (event 2, table 5.A.3), they gathered 5.0 kg of *Ipomoea* per collector in a 500-m^2 area, for a return of more than 5,200 kcal per hour spent searching, gathering, and processing. On subsequent trips, returns fell below 2,600 kcal per hour searching and handling, and the area searched steadily increased to more than 60,000 m^2. On the afternoon of event 8, foragers abandoned the search for *Ipomoea* and walked to a nearby patch of mulga where they collected *Vigna*. The next time they had access to the vehicle, they traveled not to site 1, but to site 6, ninety-five kilometers west on the Sandover.

Although the data are admittedly slender, we suspect foragers had exhausted *Ipomoea* at site 1 by midday on the third trip, or at least reduced its abundance to the point that *Vigna* in the adjacent patch became the optimal choice. If so, the subsequent trip to site 6 makes sense. Having depleted one sandhill patch, foragers then shifted their attention to another more distant one, where returns were better.[8]

Now let us examine the four cases which seem to be inconsistent with the patch choice model.

Event 3a. Foragers traveled to an isolated patch of mulga woodland (site 2), located about twenty kilometers north of Bendaijerum, well inside the sandhill habitat. There they spent more than an hour searching for *Vigna* and lizards, but with little success. The take was barely 200 kcal per forager-hr searching and handling (table 5.A.3). En route back to the settlement, they stopped to collect *Ipomoea* in a sandhill patch (event 3b, site 3) that they all knew well and through which they had passed en route to the mulga. There the

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7. In spite of the fact that the sandhill habitat is 9 km, or about two hours walk from Bendaijerum, foragers might still be expected to travel there on foot rather than operate in mulga woodland, at least under certain circumstances. Assuming the average return (E_n) from foraging in mulga woodland is 500 kcal per hr, a trip to the sandhills would have to yield better than 4,000 kcal in an eight-hour period to surpass the yield from the same time spent in the mulga. The average E_p value for sandhill patches listed in table 5.3 is about 2,900 kcal per hr, which means that foragers could travel up to 3.25 hours (ca. 16 km) to reach such a patch, spend no more than 1.5 hours searching and collecting, and still gain an E_n greater than 540 kcal per hr. Still, Alyawara foragers never traveled to the sandhills on foot from Bendaijerum during the study period. Whether this reflects a failure to conform to the predictions of the patch choice model or the absence of productive sandhill patches within a 3.0-3.5-hour radius of Bendaijerum is not clear, though for reasons outlined later in the text, we suspect that suitable patches were in fact not present.

8. If we are right, these two interpatch moves are consistent with the predictions of Charnov's (1976a) marginal value theorem (see Winterhalder, chapter 2, above).

take was more than 2,300 kcal per collector-hr on site, or about 2,000 kcal per hr, counting processing. Moreover, it had been less than a month since members of the same party had visited another sandhill patch (site 1, event 2), less than five kilometers beyond the mulga, where they gained the 5,200-kcal-per-hr return mentioned above. As records of subsequent visits to this site (events 4, 8a) clearly show, there was still much more to be collected there. Even if *Vigna* had been so abundant in the mulga patch as to require no search, the best return possible would have been no better than 1,700 kcal per hr, somewhat less than that available in adjacent sandhill patches.

Forager behavior in this instance might be seen as an attempt to obtain information on resource conditions as an aid to planning future trips. Foragers certainly knew that *Ipomoea* would ultimately be exhausted in patches near Bendaijerum, and, when it was, information on the availability of alternate resources would have been essential to future planning. Reconnaissance visits like these are to be expected, even though the immediate returns may often be comparatively low. As J. Maynard Smith (1978:34) says: "Optimal behavior depends on a knowledge of the environment, which can only be acquired by experience; this means that in order to acquire information of value in the long run, an animal may have to behave in a way which is inefficient in the short run" (see also Hitchcock and Ebert 1980).

Events 15 and 17. The exceptions in the case of events 15 and 17 may be more apparent than real. We note that from August through December, energy returns from grub-collecting trips in mulga woodland nearby doubled relative to time spent searching and gathering (table 5.A.5). This probably reflects a reduction both in search time as local soils dried and cracked over grub-infested roots, and in handling time as grubs grew in size toward the end of the larval stage (Tindale 1953). By mid-November, foragers could probably have expected average returns greater than 800 kcal per on-site hour in the mulga near Bendaijerum. If we assume they could reach productive areas in an hour's travel time, and that they could anticipate at least four hours time on site collecting, the minimum return would have been 3,200 kcal per collector-trip, or about 533 kcal per collector-hr (E_n).

Trips to sandhill patches earlier in the year certainly produced better results. On four occasions from June through August (table 5.A.3), returns from *Ipomoea* alone averaged about 2,700 kcal per collector-hr on site, or about 2,300 kcal per collector-hr, counting processing. At this rate, collectors could have driven 2.5 hours each way, spent only 1.5 hours on the patch, and still gained a net return better than 530 kcal per hour, including processing time. Even if the trip were extended to nine hours (at or near the maximum for both the ethnographer and the Alyawara), 2.2 hours collecting would have yielded an E_n return greater than 560 kcal per hr, and a total trip return greater than 5,000 kcal. This allows about 3.4 hours travel time each way. If foragers had targeted *Solanum centrale*, and located a patch which produced at the same rate as did those visited on 28 December 1974 (table 5.A.3), they could have traveled more than 3.75 hours to reach the patch, collected for less than 1.5 hours, and still gained better than 650 kcal per hr, or about 6,000 kcal total for the trip.

The problem lies in finding the appropriate patch. As we have already said, *Ipomoea* and *Solanum* are not uniformly or randomly distributed in the sandhill habitat, but are found in abundance only in disturbed areas, such as recently abandoned habitation sites or localities swept by bush fires. There were only two of the former in sandhill country near Bendaijerum. As we have already mentioned, one (site 1) may have been cleared of *Ipomoea* by mid-July. The other (Gurlanda) was seldom visited for fear of dangerous spirits, and in any case had been so thoroughly searched during the years it was occupied that it may not have had sufficient time to recover.[9] Fire-scarred sites at various successional stages are found throughout sandhill country, but are difficult to monitor. Only one road, barely passable by four-wheel-drive vehicle, transects the sandhills directly north of site 1, and it is seldom traveled. Though *Ipomoea* and *Solanum* were probably common at some sites within 3.5-4.0 hours by truck from Bendaijerum, actually *locating* one in that time would have been a chancy business. The fact that collectors were willing to travel three hours to a site 95 kilometers west of Bendaijerum (event 9) seems to us an indication of the risks involved in foraging in the sandhills north of site 1.

Given this line of reasoning, it should not be surprising that foragers collected in the sandhills only three times after August, twice in the course of trips in which the destination was determined by the ethnographer (events 12, 16), once when they evidently chose a site on the basis of information gained on a previous trip (event 13). Without such information, foragers were more assured of a good return in mulga woodland, even if they had access to a vehicle; or at least so the data suggest,

Event 10. On the occasion of event 10, women used the ethnographer's truck to reach a grub-collecting site in mulga country, but recovered only 418 kcal per collector-hr for the entire trip. Since the event took place after the apparent depletion of nearby, well-known sandhill patches, it is consistent with the argument just outlined for events 15 and 17. The implication is that the anticipated encounter rate for high-ranked sandhill resources was very low indeed.

Summary. Although the data are few, Alyawara foraging behavior seems to fit the patch choice model fairly well. On nine occasions in which foragers had free access to the ethnographer's vehicle, they made what appear to have been optimal choices concerning patch type at least five times, and possibly as many as eight times. Even the ninth case (event 3) can be seen as consistent with the model, when the need to gather information on resource condition is considered. We conclude that optimal foraging theory is likely to provide a useful framework in which to consider Alyawara subsistence strategy and tactics. Certainly it merits a more comprehensive test. The analysis also shows that the presence of motor vehicles (and other items of European technology) need not inhibit the investigation of hunter-gatherer ecology. In this case, the vehicle simply added to the range of foraging options open to the Alyawara, thereby enriching the "experimental" dimensions of the situation.

Some General Implications

To this point, we have confined our discussion of hunter-gatherer subsistence practices and optimal foraging to the Alyawara case. We now turn briefly to two more general issues: regional variation in diet, and long-term change in diet and patch use among Australian Aborigines.

Regional Variation in Diet

A comparison of the lists of plant foods used by various central Australian tribes

9. The Gurlanda locality, which includes four separate sites (Z, A-C), was occupied from 1969 to 1973. All sites show evidence that seeds were exploited during occupation, which implies heavy pressure on higher-ranked resources. Each site was abandoned because of the death of one of its occupants, a common practice among Australian Aborigines. The death which led to the abandonment of site C, the last site occupied, was of a particularly influential senior man, and informants were openly afraid of visiting this site or the surrounding area, lest they provoke the man's spirit.

shows that certain species common throughout this region were heavily exploited by some groups but ignored by others. Examples include nardoo (*Marsilea* spp.), which produces a seedlike sporocarp often identified as a staple south of the Macdonnell Ranges, 200-400 kilometers south of Alyawara territory (Horne and Aiston 1924:52-57; Spencer 1928:34-35; Worsnop 1897:81-82); and ironwood and deadfinish (*Acacia estriophiolata* and *tetragonophylla*), the seeds of which were used by the Walbiri and others in and around the Tanami Desert, 200-300 kilometers west of Alyawara country (Meggitt 1957:143 1962:5). All three species are found in the upper Sandover and Bundey river drainages, but none are identified there as edible. Nardoo even lacks a specific Alyawara name. It seems unlikely that the Alyawara fail to recognize the potential utility of these plants, especially since many are well aware of their use among other groups. In spite of this, they maintain that the plants are "not food" and refer to those who eat them as *urrupana* or "poor buggers." Similar differences in the use of plants are reported on an even larger, subcontinental scale by Golson (1971), Lawrence (1968), and Meggitt (1964). Golson, for example, says that as many as forty-five species of tree and grass seeds taken by central Australian groups are ignored by the natives of Arnhem Land, even though common there.

These differences could be attributed to cultural preference but this begs the question. We suggest that in these and other similar cases, plants are included in or omitted from the list of species culturally designated as edible on the basis of the same criteria which determine optimal diet, i.e., net returns on handling time and the abundance and accessibility of higher-ranked resources. If high-ranked resources are so abundant that returns never fall to the point where it becomes efficient to include lower-ranked items in the diet, there is no reason to define the latter as food, all else being equal. If this hypothesis were valid, we would expect that a species common in two areas but eaten in only one would have relatively high gathering and processing costs. We would also expect that lower-cost resources were more common in the area where the species in question was not used. It is interesting in this light to recall Spencer's (1928:35) remarks on nardoo. He notes that it is heavily used by the Urabunna and Dieri around Lake Eyre, but ignored by the Arunta (Aranda) farther north in favor of manyeroo (*Portulaca oleracea*, an important Alyawara seed food), "probably because [the latter] is more common and more easily collected." Spencer's observation is anecdotal, but consistent with expectations. It would be most interesting to pursue this line of argument further, not only in Australia, but with data from other hunter-gatherers, such as the !Kung, among whom dietary differences of this type are well documented (e.g., Lee 1979).

Long-Term Change in Diet and Land Use

In recent years, an interesting controversy has developed over the pattern and rate of human colonization of Australia. Birdsell (1957) originally argued that within five thousand years after man's initial landing, an event now thought to have taken place at least fifty thousand years ago (Jones 1979; White and O'Connell 1979), all parts of the continent, including the continental islands of New Guinea and Tasmania, were already populated at levels approaching those recorded at the time of European contact. This idea seems to have been accepted tacitly by prehistorians, who until recently treated the archeological record as if it provided incomplete but plausible support for Birdsell's position (e.g., Jones 1973:281; Mulvaney 1975:161).

Bowdler (1977) has challenged this line by arguing that the available archeological data are better seen as showing that the earliest Australians occupied coastal and riverine habitats first, and only later moved to other areas, including the arid central desert, probably after 15,000 BP. Jones (1979) rightly remarks that although occupation of the continental core is indeed late (no earlier than 10,000 BP on present evidence; see Gould 1977), the archeological record shows that several areas which were neither coastal nor riverine were inhabited before 20,000 BP, including the mountains of New Guinea and east central Queensland (White, et al. 1970; Mulvaney and Joyce 1965), the Nullarbor Plain of south Australia (Wright 1971), and parts of southwestern Australia (Dortch 1976). Jones and Bowdler agree that there is probably a causal connection between the beginning of a period of widespread aridity dated 16,000-17,500 BP (Bowler, et al. 1976), the first use of seeds, as evidenced by the discovery of grinding tools in 15,000-18,000-year-old deposits in western New South Wales and Arnhem Land (Allen 1972 1974; Kamminga and Allen 1973, cited in Bowdler 1977:235-36), and the initial occupation of the central desert, but they are not specific about the details of this relationship.

Optimal foraging theory gives us some insight into the processes which might have been operating in this situation. We suggest that on landing, Australian Aborigines first occupied only those habitats which produced the best return for foraging effort. More precisely, the order in which habitats or habitat types were occupied should have varied directly with the net energy gained from exploiting them, and inversely with their distance from the original landing point(s). Habitats in which energy returns were comparatively low should have remained unoccupied until returns in "better" habitats fell to the same level (Fretwell and Lucas 1969). Movement into new habitats should have been a function of (a) population increase which depleted resources in occupied habitats to the point where such movement became more efficient, or (b) climatic or other environmental change which either differentially reduced returns in the occupied habitats, or increased those available in the unoccupied ones. Within each habitat, resources should have been exploited in order of net return on handling time, highest-ranked resources first. The same pattern should be evident on a continental scale as well, i.e., low-cost/high-return resources taken relatively early in the past, high-cost/low-return resources relatively later. Again, depletion of high-ranked resources through population growth or environmental change should have been the critical factor forcing increased diet breadth.

All this means that although coastal and riverine habitats may have been *among* the first occupied, it need not have been to the exclusion of other habitats, nor need it have been the result of a "preadaptation" to aquatic resources, as Bowdler (1977:221) implies. Energy budgets are more likely to have been important here than any presumed traditional economic orientation. On the other hand, these same propositions are consistent with Bowdler's suggestion that central Australia was unoccupied until quite late. In light of the Alyawara data, it seems unlikely that Aborigines could have lived there (certainly not at the densities recorded historically) unless they had access to seeds, which should also be late. We propose that the onset of arid conditions 17,000-18,000 BP led to critical reductions in the abundance of high-ranked foods and favored the adoption of more expensive items, including seeds. Once the technology for processing seeds was available, it was possible for Aborigines to move to previously uninhabited or sparsely inhabited parts of the continent. It is consistent with expectations based on the optimal diet model that seeds were subsequently the first resources dropped from the diet when European rations (which are high ranked in cost-benefit terms relative to native resources) became available in quantity.

It is interesting to note that cycads (*Macrozamia* spp., *Cycas* spp.), a seasonal staple in many areas of tropical Australia, but one which may be even more expensive than seeds because of the elaborate processing it requires, first appears in the Australian diet even later than seeds, possibly as late as 5,000 BP (Beaton 1977). This also seems consistent with expectations based on the optimal diet model. We wonder how widely this model can be applied in the explanation of long-term changes in diet, including those involving the adoption of domesticates.

Summary

We began this chapter by asking why the Alyawara had effectively stopped eating native grass and tree seeds, resources which had been staples in the traditional diet and which continue to be locally abundant today. Analysis of the available data on modern plant collecting practices strongly suggests that this behavior can be understood in terms of a model of optimal diet derived from the theory of optimal foraging. It further suggests that the choice of location in which to search for plant foods can be explained in terms of a second model (i.e., patch choice) also derived from this theory. Having presented this argument, we then considered its implications for the explanation of synchronic and diachronic variability in seed use by Australian Aborigines. Although our treatment was cursory, it was sufficient to suggest that optimal foraging theory may provide a useful means of investigating such variability.

Overall, this discussion provides empirical support for the argument that hunter-gatherer subsistence practices can be viewed profitably in terms of the same general theory now being applied by evolutionary ecologists to the study of feeding strategies among nonhuman organisms. This does not mean that such theory will necessarily provide complete and comprehensive explanations for the full range of foraging practices observed or inferred for past and present hunters. Other social and cultural variables will certainly have structured these practices to a significant degree. The value of such theory lies in its role as a reference dimension, as a source of testable hypotheses about the organization of subsistence-related behavior in a wide range of environmental, technological, and social circumstances. By testing such hypotheses, we should be able to distinguish those aspects of behavior motivated by the principles of optimal foraging from those which are shaped by other variables, and, having isolated the latter, seek explanations for them in other terms.

Appendix

Table 5.A.1

Some Animal and Plant Foods of the Alyawara

ANIMALS	
Mammals (> 15 species)	
Red kangaroo	*Megaleia rufa*
Euro or wallaroo	*Macropus robustus*
Hare wallaby	*Lagorchestes* spp.
Nail-tailed wallaby	*Onychogalea* sp.
Rat kangaroo	*Bettongia* spp.
Bandicoots	*Perameles* sp. *Macrotis lagotis*
Brush-tailed possum	*Trichosurus vulpecula*
Birds (> 10 species)	
Emu	*Dromaius novae-hollandiae*
Plains bustard	*Eupodotis australis*
Reptiles (> 5 species)	
Pirenti	*Varanus giganteus*
Sand goanna	*V. gouldii*
---	*Amphibolarus* sp.
Carpet python	*Aspidites* sp.
Insects (> 5 species)	
Witchitty grubs	*Cossidae* (larvae, probably *Xyleutes* sp.)
PLANTS	
Seed producers (39 species)	
Acacias	*Acacia* spp., esp. *aneura, kempeana, coriacea, cowleana, dictyophleba*
Kurrajong	*Brachychiton gregorii*
Gums or eucalypts	*Eucalyptus* spp., esp. *microtheca*
Chenopods	*Chenopodium* spp.
Grasses	*Eragrostis eriopoda, leptocarpa* *Panicum australiense, decompositum*
Manyeroo	*Portulaca oleracea*
Root producers (5 species)	
Bush potato	*Ipomoea costata*
Native yam	*Vigna lanceolata*
Fruit producers (27 species)	
Native plum	*Canthium latifolium*
Native oranges	*Capparis* spp.
Konkaberry	*Carissa lanceolata*
Solanums	*Solanum* spp., esp. *centrale*

Note: Figures in parentheses indicate the total number of species identified as edible. Named taxa are those most often mentioned by informants in response to questions about pre-European diet. Most plant species listed were probably staples. Sources: O'Connell, Latz, and Barnett, n.d.; Allen Newsome, personal communication.

Table 5.A.2

Quantitative Data on Some Plant Collecting Trips Originating at Bendaijerum, 1973-75

Event	Date	Habitat	Site	Distance Traveled (km)	Total Trip Time (hr) $[T_t + T_s + T_g]$	Mode of Travel	Time on Site (hr) $[T_s + T_g]$	No. of Collectors	Main Items Collected	Kg/Collector	Additional Processing Time (hr) $[T_p]$	Kcal/kg $[E'_i]$	Kcal/Forager-hr, incl. Travel, Search, Gathering, and Processing $[E_n = E/(T_t + T_s + T_g + T_p)]$
1	2 Sept 73	SH	1	50		V	1.5	5	*Solanum centrale*	2.0	0.0	2992	
2	11 May 74	SH	1	50	3.5	V	1.0	3	*Ipomoea*	5.0	0.5	1563	1,954
3a	2 Jun 74	MW	2	45	6.0	V	1.17	4	*Vigna*	0.13	0.0	862	
									Varanus	0.13	0.0	1050	617
3b	2 Jun 74	SH	3				1.5	3	*Ipomoea*	2.3	0.23	1563	
4	28 Jun 74	SH	1	50	7.5	V	4.5	7	*Ipomoea*	8.9	0.89	1563	1,658
5	6 Jul 74	MW	4		5.0	F		7	*Vigna*	2.14	0.0	862	
									Amphibolarus	0.14	0.0	1050	413
									Varanus	0.07	0.0	1050	
6	10 Jul 74	MW	4		8.0	F		4	*Vigna*	2.25	0.0	862	
									S.cf.ellipticum	0.25	0.0	508	325
									Amphibolarus	0.13	0.0	1050	
									Varanus	0.38	0.0	1050	
7	10 Jul 74	FP	5		8.0	F		5	*Cyperus*	1.6	0.4	3326	634

8a	15 Jul	74	SH	1	50	8.0	V	3.0	8	*Ipomoea*	5.5	0.55	1563	1,039
8b	15 Jul	74	MW	1				0.6	6	*Vigna*	0.33	0.0	862	
9	10 Aug	74	SH	6	190	9.0	V	3.0	7	*Ipomoea*	5.0	0.5	1563	823
10	22 Aug	74	MW	7	25	6.75	V	4.5	7	*Cossidae*	1.0	0.0	2600	418
										Amphibolarus	0.14	0.0	1050	
										Varanus	0.07	0.0	1050	
*11	7 Oct	74	MW	7	25	4.5	V	3.5	2	*Acacia aneura*	0.5	2.0	3778	579
									5	*Cossidae*	0.72	0.0	2600	
*12	23 Oct	74	SH	8	60	4.5	V	1.5	2	*Ipomoea*	4.0	0.4	1563	1,276
*13a	7 Nov	74	SH	2	60	5.0	V	0.25	2	*Acacia cowleana*	0.1	0.4	3589	
13b	7 Nov	74	SH	8				1.0	8	*A. coriacea* (unripe)	1.4	0.0	2600	787
13c	7 Nov	74	SH	9				0.33	3	*Ipomoea*	0.17	0.02	1563	
14	14 Nov	74	MW	4		6.0	F		6	*Cossidae*	1.1	0.0	2600	520
										Amphibolarus	0.25	0.0	1050	
15	15 Nov	74	MW	7	30	7.0	V	5.0	5	*Cossidae*	1.54	0.0	2600	587
										Varanus	0.1	0.0	1050	
*16a	28 Dec	74	SH	2	45	3.5	V	1.0	3	*S. centrale*	1.5	0.0	2992	2,052
16b	28 Dec	74	SH	3				0.75	5	*S. centrale*	0.9	0.0	2992	
17	30 Dec	74	MW	7	30	5.5	V	4.5	4	*Cossidae*	1.75	0.0	2600	827
18	19 Feb	75	MW	4		8.5	F		7	*Cossidae*	0.66	0.0	2600	251
										Vigna	0.14	0.0	862	
										Amphibolarus	0.14	0.0	1050	
										Varanus	0.14	0.0	1050	
19	27 Feb	75	MW	4			F		2	*Vigna*	0.5	0.0	862	
										Amphibolarus	0.75	0.0	1050	

Notes on Table 5.A.2

Abbreviations

SH = sandhills
MW = mulga woodland
FP = riverine floodplains
V = motor vehicle
F = foot
T_t = time traveling to and from foraging site(s)
T_s = time searching foraging site(s)
T_g = time gathering resources
T_p = time processing resources for consumption after collecting
E^*_i = mean calories (kcal) per kilogram of resource type i (see table 5.4)
E = total calories recovered per collector per trip
E_n = ratio of energy gained per unit of time invested in foraging, including travel time to foraging site(s)

Starred trips (*) are those in which the ethnographer played a significant role in determining destination and/or resources taken.

Collecting events

1. Site 1 is an abandoned campsite. *Ipomoea* and *Solanum* flourish there after rain.

2. Collectors arranged trip late in the day; traveled direct to the collecting site. The encounter rate for *Ipomoea* was at its highest. Collectors dug all roots within 500-m^2 area. Collecting stopped because of darkness. Total party: 7 women, 5 children.

3. Collectors traveled to a patch of mulga woodland in sandhill country; foraged on foot for *Vigna* over 75,000 m^2 area; ate small quantities of *Carissa* and *Lysiana* berries while walking. At end of walk, they expressed surprise at low returns. On route back to Bendaijerum, they collected *Ipomoea* in a 500 m^2 patch along the roadside. Time on site at this location includes about one hour search time. Total party: 8 women, 5 children, 1 infant.

4. Collectors traveled directly to site. Foraged on foot over 20,000 m^2; gathered 6.3 kg *Ipomoea* per collector in 2.17 hr. Foragers ate small quantities of *Solanum* fruit and *Leichhardtia* leaves encountered while walking. After a 30-min lunch break, they foraged over 25,000 m^2; took 1.5 kg *Ipomoea* per collector in 1.75 hr. Total party: 7 women, 7 children, 1 infant.

5. Site 4 is in mulga woodland east of Bendaijerum. No data on location or size of specific site(s) visited by foragers. Total party: 7 women, 1 infant.

6. *Solanum* cf. *ellipticum* was originally identified as *S. cleistogamum*, but the latter does not appear in Chippendale (1971). The species collected resembles *ellipticum*. Note also that the caloric value reported for *ellipticum* (508 kcal per kg, ref. Dadswell 1934, cited in N. Peterson 1978:28-29) is low by comparison with other solanums, especially *S. centrale*. A value equivalent to the latter would raise the E_n figure to 402 kcal per collector-hr. Total party: 4 women.

7. Site 5 is on the Bundey River, west of Bendaijerum. Total party: 6 women, 5 children, 1 infant.

8. After arrival at the collecting site, operators foraged over 60,000 m^2, recovered 5.5 kg *Ipomoea* per collector in 3 hr. Ate small quantities of *Solanum* fruit (both *centrale* and *ellipticum*) and *Leichhardtia* fruit and leaves as they walked. After a brief meal stop, collectors moved into a stand of mulga woodland, took 0.33 kg *Vigna* per collector in 0.6 hr. All *Vigna* were eaten at collecting site. Total party: 8 women, 6 children, 3 infants.

9. Collectors traveled 95 km by road to a site west of the Sandover River, well known to several members of party. Spent only three hours on site before returning to Bendaijerum. Total party: 9 women, 4 children, 3 infants.

10. Collectors visited two sites in mulga woodland. On arrival at first, collectors dispersed. One group of three collectors dug 1.5 kg grubs from 17 shrubs (all *Acacia kempeana*) scattered over 10,000 m^2 in 1.5 hr. One-third of the total was taken from roots of first shrub, remainder from the other sixteen. About 2-5 min were spent digging at each shrub. Children collected 3.0 kg *Leichhardtia* fruit at this site. Entire party then moved to a site 1 km distant where more grub collecting took place. Total party: 8 women, 7 children.

11. Women offered to demonstrate collecting techniques for *Acacia aneura*. Party traveled by truck to a point about 12 km east of Bendaijerum, where two women spent 1.82 hr gathering 1 kg of seed (see notes, table 5.3; also O'Connell, Latz, and Barnett, n.d.). Other women in party observed demonstration for a time, then went off to collect cossid larvae. Four women took 2.4 kg grubs in 1.7 hr; one woman took 1.2 kg in 1.75 hr. Total party: 7 women, 2 children, 2 infants.

12. *Ipomoea* tubers were unexpectedly encountered just north of site 1 on a trip organized by O'Connell and botanist Peter Latz for purposes of collecting plant specimens. Two Alyawara men acting as guides and informants collected tubers plus small quantities of unripened *A. coriacea* seed.

13. Women were asked for a second demonstration of seed collecting. At their request, they were driven to the sandhill habitat north of Bendaijerum, stopping twice en route to collect *A. cowleana* seeds. Two women performed each demonstration; all others in party observed. On arrival at site 8, the same one visited on event 12, all debarked and spent ca. 1 hr collecting unripe *A. coriacea* seed pods. Total 34 kg pods, containing an estimated 7-10 kg seeds, were loaded for return trip, but large numbers were also split and the seeds eaten on the spot. On return trip, women stopped briefly at site 9 to look for *Ipomoea*. More than 8,000 m^2 were searched, but though plants were common, tubers themselves were few. Total party: 8 women, 6 children, 2 infants.

14. Total party: 6 women, 1 infant.
15. Total party: 6 women, 4 children.
16. Total party: 6 women, 3 children, 1 infant.
17. Total party: 4 women, 9 children.
18. Total party: 8 women, 1 infant.
19. Total party: 2 women.

Table 5.A.3

Energy Returns from Sandhill and Mulga Woodland Patches

Patch Type	Event	Date	Site	Main Item Collected	Kcal/Forager-hr in Patch, including Processing [$E_p = E/(T_s + T_g + T_p)$]	E^*_i/h_i
Sandhill	1	2 Sept 73	1	*Solanum centrale*	3,989	5,984
	2	11 May 74	1	*Ipomoea*	5,210	6,252
	3b	2 Jun 74	3	*Ipomoea*	2,077	6,252
	4	28 Jun 74	1	*Ipomoea*	2,576	6,252
	8a	15 Jul 74	1	*Ipomoea*	2,422	6,252
	9	10 Aug 74	6	*Ipomoea*	2,232	6,252
	12	23 Oct 74	8	*Ipomoea*	3,290	6,252
	13a	7 Nov 74	2	*Acacia cowleana*	552	552
	13b	7 Nov 74	8	*Acacia coriacea*	3,640	4,333
	13c	7 Nov 74	9	*Ipomoea*	759	6,252
	16a	28 Dec 74	2	*Solanum centrale*	4,488	5,984
	16b	28 Dec 74	3	*Solanum centrale*	3,590	5,984
Mulga woodland	3a	2 Jun 74	2	*Vigna* *Varanus*	212	1,724 4,200
	5	6 Jul 74	4	*Vigna* *Varanus* *Amphibolarus*	413	1,724 4,200 4,200
	6	10 Jul 74	4	*Vigna* *S. cf. ellipticum* *Varanus* *Amphibolarus*	325	1,724 504 4,200 4,200
	8b	15 Jul 74	1	*Vigna*	474	1,724
	10	22 Aug 74	7	*Cossidae* *Varanus* *Amphibolarus*	418	1,486 4,200 4,200
	11	7 Oct 74	7	*A. aneura* *Cossidae*	529	580 1,486

Table 5.A.3 (continued)

Patch Type	Event	Date	Site	Main Item Collected	Kcal/Forager-hr in Patch, including Processing [$E_p = E/(T_s + T_g + T_p)$]	E^*_i/h_i
Mulga woodland (continued)	14	14 Nov 74	4	*Cossidae* *Amphibolarus*	520	1,486 4,200
	15	15 Nov 74	7	*Cossidae* *Varanus*	587	1,486 4,200
	17	30 Dec 74	7	*Cossidae*	827	1,486
	18	19 Feb 75	4	*Cossidae* *Vigna* *Varanus* *Amphibolarus*	251	1,486 1,724 4,200 4,200

Note: Time spent traveling to and from patch not included in calculation.

Table 5.A.4

Quantitative Data on Collecting and Processing Time: Net Energy Returns for Some Alyawara Plant and Animal Foods (W = winter, S = spring and/or early summer)

	Collecting and Processing Time (hr/kg) [$h_i = g_i + r_i$]	Kcal [E^*_i]	Net Return Rate on Resource Once Encountered [E^*_i/h_i]	Rank	Period Available W	Period Available S
Sandhill						
Ipomoea costata	0.25	1,563	6,252	1	X	X
Solanum centrale	0.50	2,992	5,984	2	X	X
Acacia coriacea (unripe)	0.60	2,600	4,333	3		X
Varanus sp. *(cf. gouldii)*	0.25	1,050	4,200	4	X	X
Vigna lanceolata	0.50	862	1,724	5	X	X
A. coriacea (ripe)	>5.25	3,551	< 676			X
A. aneura	6.50	3,778	580			X
Grass seeds	6.00	3,450	575	6	X	X
A. cowleana	6.50	3,589	552			X
Other acacias	6.50	3,500	538			X
Mulga woodland						
Amphibolarus sp. *Varanus* sp.	0.25	1,050	4,200	1	X	X
Vigna lanceolata	0.50	862	1,724	2	X	X
Cossid larvae	1.75	2,600	1,486	3	X	X
A. aneura	6.50	3,778	580	4		X
Grass seeds	6.00	3,450	575		X	X
River floodplain						
Cyperus sp.	0.75	3,326	4,435	1	X	X
Grass seeds	6.00	3,450	575	2	X	X

Notes on Table 5.A.4

Caloric Values

Caloric values for reptiles *Amphibolarus* sp. and *Varanus* sp. are taken from Meehan (1977b); those for *Vigna*, *Acacia coriacea* (ripe), *A. cowleana*, "other acacias," grass seeds, and solanums from N. Peterson (1978); those for *Ipomoea*, *A. aneura*, *A. coriacea* (unripe), *Cyperus* from P. Latz and P. Maggiore (Latz, personal communication). Values for cossidae calculated as follows:

1. Cossid larvae are said to contain about 50% fat, 50% protein (A. Hamilton 1971, cited in N. Peterson 1978:28-29). We assume these are dry weight proportions.
2. The moisture content of morphologically similar "meal worms" (species unknown) from a Salt Lake City pet store was found to be about 60% (A. Mahoney, Department of Nutrition and Food Sciences, Utah State University, Logan; personal communication).

3. Standard caloric equivalents for fats and proteins are about 9 kcal/g and 4 kcal/g, respectively (Merrill and Watt 1955).

Thus, we estimate 1,000 g live weight of cossid larvae equal 400 g dry weight, including 200 g fat and 200 g protein, or about 2,600 kcal. Cummins and Wychuck (1971:128-29) calculate a similar figure for larvae of "grain beetles" (*Tenebrio* spp.).

Collecting and Processing Time

Estimates for seeds are based on controlled demonstrations. They include collecting and processing time (g_i, p_i), but no search time (T_s). Estimates for all other resources are based on observations in which search time and collecting time were not always clearly separated. Note: h_i (handling time) = $g_i + p_i$.

Amphibolarus sp., *Varanus* sp.: These are small lizards, average weight 0.5 kg, often encountered in mulga woodland and sandhill country. Once spotted, they are treed, or trapped in burrows, and killed, usually within 5 min of contact. They are roasted whole in ashes on open hearths. Est. h_i = 0.25 hr/kg.

Cossid larvae: These are small grubs, 4-10 cm long. They are dug from shallow roots of *A. kempeana* or *Cassia* spp., lightly roasted in hot ashes. p_i is minimal; g_i estimated from two incidents:

1. Event 10: 3 collectors took 0.5 kg larvae from roots of one *A. kempeana* shrub in 0.33 hr. T_s = 0.0; thus, g_i = 2.0 hr/kg.
2. Event 15: 5 collectors foraged for grubs in mulga woodland. $T_s + g_i$ were recorded for each collector during two separate foraging bouts:

Collector		hr	kg	$(T_s + g_i)$/kg
Minnie	am	2.2	0.76	2.89
	pm	1.8	0.53	3.40
Angelina	am	2.33	1.10	2.12
	pm	2.25	0.71	3.87
Maggie	am	2.33	0.32	7.28
	pm	2.25	1.00	2.25
Elsie	am	2.33	0.32	7.28
	pm	2.25	1.20	1.88
Dollie	am	2.2	1.20	1.83
	pm	1.8	0.53	3.40

The range is wide, but minimum $T_s + g_i$ figures are less than 2.0 hr/kg; thus we take g_i = 1.75 hr/kg as a best approximation for this resource.

Ipomoea costata: These tubers grow on rooted stems of rhizomes which extend from a central bush or shrub, and are found ca. 0.6-1.0 m below ground surface. Tubers vary greatly in size but average 0.4 kg each. During event 2, three women collected 15 kg in one hour. T_s = 0.0; thus g_i = 0.2 hr/kg. Tubers are scraped free of grit and roasted in small, specially prepared pits. We estimate p_i = 0.08 hr/kg. $g_i + p_i = h_i$ = 0.28 hr/kg; rounded to nearest quarter hour, 0.25 hr/kg. Data from event 3 yield the same estimate.

Solanum centrale, ellipticum: These small fruit (ca. 2 cm dia) are found on low bushes and are picked individually by hand. Bushes were common at sites 2 and 3 on 28 Dec 74 (event 16), and search time was correspondingly quite low. At site 2, three women took 4.5 kg *S. centrale* in one hour; thus $T_s + g_i$ = 0.67 hr/kg. At site 3, five women took 4.5 kg in 0.75 hr; thus $T_s + g_i$ = 0.83 hr/kg. Therefore, we estimate g_i alone = 0.50 hr/kg, rounding to nearest quarter hour. Once collected, fruit were always eaten without further processing, thus $g_i + p_i$ = 0.5 hr/kg.

Vigna lanceolata, Cyperus sp: *Vigna* are 15-20 cm long, 2-4 cm in diameter; *Cyperus* are 1-2 cm in diameter. Both are found close to the ground surface; *Vigna* usually as an isolate, *Cyperus* often at high densities. We estimate g_i greater than that for *Ipomoea*, or about 0.5 hr/kg. *Vigna* requires no processing other than hand rubbing to remove grit; thus $g_i + p_i$ = 0.5 hr/kg. The thin skin on *Cyperus* must be rubbed off by hand. Estimated p_i = 0.25 hr/kg; thus $g_i + p_i$ = 0.75 hr/kg.

Acacia spp: Seeds occur in pods 2-20 cm long, depending on the species. When pods are dry, collectors pull boughs from tree, beat with sticks to separate pods, beat and crush pods to release seeds, winnow seeds from pod fragments in carrying trays. Seeds are parched in ashes; then ground on flat or grooved slabs with handstones. Quantitative data on these observations come primarily from three incidents:

1. *A. aneura*/event 11: two women gathered and winnowed 1 kg seed in 1.82 hr (g_i = 3.64 hr/kg). Many pods were too green to be cracked, and were set aside to dry. If collectors had returned to gather seeds from these, the same amount would have been recovered in half the time. Thus g_i (combined) = 2.64 hr/kg. Parching time = 0.06 hr/kg. Brief demonstration of grinding indicates est. rate of 165 g/hr or 6.06 hr/kg. P. Latz

(personal communication) says this figure may be too high. His experiments suggest a grinding rate of 3 hr/kg. Combining these data with our own, we estimate p_i (including parching) = 4 hr/kg; thus $g_i + p_i = 6.64$ (rounded = 6.5 hr/kg).

2. *A. cowleana*/event 13a: two women collected and winnowed 200 g of seed in 0.25 hr (g_i = 2.5 hr/kg). Assuming p_i the same as that for *A. aneura*, $p_i + g_i$ = 6.5 hr/kg.
3. *A. coriacea* (ripe)/event 13b: two women collected and winnowed 600 g of seed in 0.375 hr (g_i = 1.25 hr/kg). Assuming p_i the same as that for *A. aneura*, $p_i + g_i$ = 5.25 hr/kg. Since *A. coriacea* seeds are very hard, grinding may be preceded by a pounding step. Processing time will be correspondingly higher.

Most other acacias should have seed-handling times comparable to *A. cowleana*. Note that *A. coriacea* seeds can also be eaten without grinding, just before they ripen fully. Seeds are collected in pods, warmed or lightly parched in ashes, then stripped out by hand and eaten. During event 13b, eight women collected more than 34 kg of pods in 1 hour, stripped and ate many more while doing so. Very little search time was involved. We estimate $g_i + p_i$ = approx. 0.60 hr/kg.

Grass seeds: No quantitative data available for the Alyawara. Figures reported by Brokensha (1975:25) from elsewhere in central Australia, coupled with Tindale's (1974:94-106 1977 n.d.) descriptive comments indicate h_i = approx. 6.0 hr/kg.

Table 5.A.5

Energy Returns per Forager-Hour on Site for Trips in Mulga Woodland Involving Motor Vehicle Transport

Event	Date	Kg/Collector	Time on Site Away from Vehicle (hr)	Kcal/Forager-hr on Site
10	22 Aug 74	1.0	4.5	572
11	7 Oct 74	0.72	3.0*	624
15	15 Nov 74	1.54	5.0	806
17	30 Dec 74	1.75	4.5	1,014

Note: Returns listed are for cossid larvae. Travel to and from collecting site not included in calculation. *Estimate omits time collectors spent watching seed collecting demonstration.